ASPECTS OF THE REPRODUCTIVE BIOLOGY OF

FEMALE SNOW CRABS, *CHIONOECETES BAIRDI*,

FROM PRINCE WILLIAM SOUND, ALASKA

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ASPECTS OF THE REPRODUCTIVE BIOLOGY OF FEMALE SNOW CRABS, *CHIONOECETES BAIRDI*, FROM PRINCE WILLIAM SOUND, ALASKA

A

THESIS

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By

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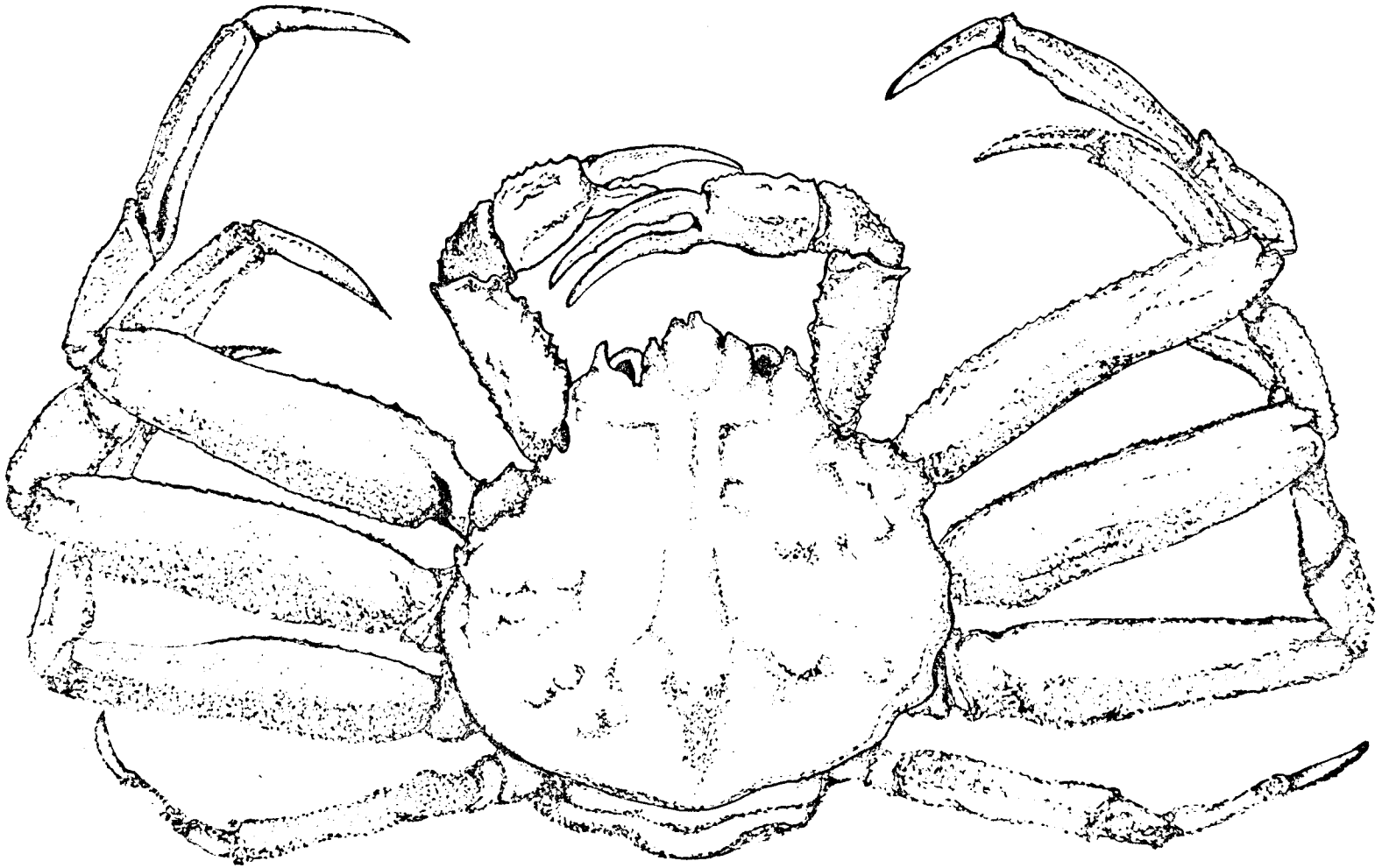

Frontispiece. Adult female snow crab, *Chionoecetes bairdi*.

ABSTRACT

The reproductive biology of the female snow crab, *Chionoecetes bairdi*, from Prince William Sound, Alaska is examined. Size at 50% maturity is 80 mm carapace width. All but a few females undergo a terminal anecdysis after maturity. Primiparous spawners molt to maturity and mate in winter or early spring while multiparous spawners extrude their eggs in May. Egg hatching occurs in both groups in April or May. All recently molted females and 90% of the old shell females are ovigerous. Egg number decreases from an average of 169,000 eggs per female after extrusion to 133,000 eggs per female before hatching. The ratio of females to males increases with size. This relationship is used to predict a ratio of 2.1 females per male at 96 mm, the average size of adult females. A comprehensive bibliography is given on the genus *Chionoecetes*.

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INTRODUCTION

I. World Distribution and Importance of the Genus *Chionoecetes*

The crabs of the genus *Chionoecetes* Kroyer have become a focal point for worlwide scientific interest in recent years. This is due primarily to the importance of these crustaceans as fishery resources in the western Atlantic and northern Pacific Oceans where they are exploited by Japan, Russia, Korea, the United States, and Canada (Watson, 1969a).

Additional interest has developed in the physiological processes of *Chionoecetes* as a deepwater poikilotherm, particularly its adaption to cold water (Scholander *et al.*, 1953; McLeese and Watson, 1968; Behrisch, 1972), temperature resistance (McLeese, 1968), ionic and osmotic regulation (McKay and Prosser, 1970), and neuromuscular physiology (Linder, 1973).

Garth (1958) classified the genus as follows:

Class: Crustacea
Sub-class: Malacostraca
Order: Decapoda
Sub-order: Brachyura
Super-family: Oxyrhyncha
Family: Majidae
Sub-family: Oregoniinae

In addition to *Chionoecetes*, the sub-family Oregoniinae also includes the genera *Hyas* and *Oregonia*.

The five species of *Chionoecetes*, along with their geographic and depth distribution (Garth, 1958 unless otherwise noted) are listed in Table 1. Many common names have been applied to these animals

Table 1. *Chionoecetes* spp. and their distribution.

Species	Depth (f)	Geog. Distribution
C. opilio (O. Fabricius)	7-85	Bering Sea, Arctic Ocean, North Atlantic Ocean from West Coast Greenland to Casco Bay, Maine
C. o. elongatus Rathbun	to 1,215	Sea of Japan Okhotsk Sea
C. bairdi Rathbun	shoalwater to 259	Bering Sea to California (Hosie and Gaumer, 1974)
C. tanneri Rathbun	29-1,062	Washington to Lower California
C. angulatus Rathbun	49-1,625	Bering Sea to Oregon
C. japonicus Rathbun	225-1150	Sea of Japan (Watson, 1969a; Fukataki, 1965)

with spider crab and tanner crab most commonly used. Members of the genus *Chionoecetes* are marketed in the United States under the name snow crab which will be used in this thesis to refer to all species.

Three snow crabs are of current major commercial importance (Brown, 1971). *C. opilio elongatus* is harvested in the Sea of Japan; *C. opilio* is harvested by Japanese and Russian fishermen in the Bering Sea, by Canadian fishermen in the northwest Atlantic, and insignificantly by Americans. *C. bairdi* is harvested by Alaskan and Japanese fishermen in the Bering Sea and by Alaskans in the Gulf of Alaska.

Japan's total annual snow crab catch reached a peak of 136 million pounds in 1968 and dropped to 117 million pounds in 1970 (FAO, 1970). The Canadian Atlantic fishery grew from 1 million pounds in 1965 to 18 million pounds in 1968 (Watson, 1970). Later tagging studies (Watson, 1971b) showed these stocks were being heavily utilized. In the north Pacific Ocean adjacent to Alaska, Japanese and Russian fisheries in the Bering Sea have historically dominated the snow crab catch accounting for more than 90% of the cummulative landings for this area (Buck, 1973).

II. Development of the Alaskan Snow Crab Fishery

Effort by U.S. fishermen to harvest snow crab in Alaska was almost non-existent until 1968. The Alaskan snow crab catch, of which 95% is *C. bairdi* (Brown, 1971), increased dramatically from 118,000 pounds in 1967 to 60 million pounds in 1973 (Alaska Department of Fish and Game, 1973).

The rapid increase in the catch is due to several factors. The king crab (*Paralithodes camtschatica*) harvest began a steady four-year decline from its peak of nearly 160 million pounds in 1966 to about 50 million pounds in 1970. During this same period, the snow crab harvest increased by over 100 times. This increase may be attributed to a shift in fishing effort from king crab and salmon toward snow crab (Brown, 1971) and an apparent increase in abundance of snow crab related to the declining abundance of king crab (Gulland, 1972). Snow crab fishing also provides additional income to fishermen during the winter season when king crab and salmon are not being harvested in most of the state.

Snow crab currently ranks third among the state's shellfishes in weight of harvest and second in value to the fishermen at about 11 million dollars. With the exception of 1970 and 1971, the catch has approximately doubled each year since 1967. At this rate of expansion, the 1974 catch would have equaled or exceeded the suggested sustainable yield of 100 million pounds for the eastern Pacific region (Gulland, 1972). It now appears that the sustainable yield may be well below 100 million pounds. The Kodiak, Prince William Sound, and Cook Inlet fisheries are remaining at or below their 1973 harvest levels (Munro, 1974) and the 64 million pound harvest in 1974 is only five percent above that for 1973.

The snow crab fishery based at Kodiak Island has always been the largest in the state, accounting for 50 to 60% of the total catch in most years (Brown, 1971). The Cook Inlet fishery was initially the

second largest with the Prince William Sound fishery, based at Cordova, third. The Cordova fishery has now expanded outside Prince William Sound into the Gulf of Alaska between Cape Cleare and Cape St. Elias. The present fishery within the Sound is primarily carried out by the small boats, with larger boats fishing the outside waters. With the expansion of the fishery into the Gulf of Alaska, the snow crab harvest for the Cordova area rose to second largest in the state, accounting for 25% of the total catch in 1973. The Cook Inlet fishery was third in size with about 17% of the 1973 harvest. The Alaska Penninsula area harvest surpassed both Prince William Sound and Cook Inlet in 1974.

Exploratory fishing carried out by the National Marine Fisheries Service (NMFS) in 1968 indicated that Prince William Sound and the adjacent Gulf of Alaska area ranked fourth in the state in abundance of snow crab (Maturgo, 1972).

III. Research Background

From a management standpoint, it is important that biological information be collected before the catch reaches or exceeds the maximum sustainable yield (Kasahara, 1972).

Studies conducted after 1966 on declining king crab stocks demonstrated that in some instances the effects of intense fishing pressure were visible as changes in the reproductive capability of the population. These studies indicated biological areas where research should be done on stocks before they became heavily exploited.

McMullen and Yoshihara (1969) found a recognizable decrease in the proportion of ovigerous female king crab in some areas and attributed it to the removal of large numbers of adult males. Kurata (MS, 1961) and McMullen (1969) suggest that only female king crabs which mate soon after molting will produce a clutch of fertile eggs. Otherwise the eggs either disintegrate or are resorbed by the ovary (McMullen, 1969; McMullen and Yoshihara, 1969). In addition, Powell and Nickerson (1965) demonstrated that female king crab will not mate with males smaller than themselves and they cite evidence from other sources that the smaller males may not always be able to adequately fertilize females. In this male-only fishery the average size (age) of males was reduced over time, thus limiting the number of large females that could successfully mate, and increasing the proportion of small males that are reproductively less effective.

Kingsbury and James (1971) detected a large increase in the number of females per male (sex ratio) in certain areas—probably due to removal of males by the fishery. This change in sex ratio should eventually decrease the probability of a female mating and, therefore, increase the chance of finding non-ovigerous females in the population.

It is suspected that the reproductive capability of snow crab will be impaired in a way similar to king crab by the removal of large adult males by the fishery. However, because of differences in biology between these two crabs, it is not clear exactly where this change will first become visible. In addition to the percent of females with eggs, egg number, and sex ratio (studies suggested from

previous king crab research), I examined the size at maturity, the phenomenon of the terminal molt in females, and the reproductive cycle in general.

The reproductive cycle of *C. opilio*, has been studied extensively in Canada (Brunel, 1961, 1962; Watson, 1969b, 1970, 1971a) and Japan (Yoshida, 1941; Ito, 1963, 1967; Kon and Nanba, 1968). This data will provide a comparison with information about *C. bairdi*.

Material published on reproduction in *C. bairdi* is limited to the size at maturity in males (Brown and Powell, 1972) and a general life history model including reproduction conducted in Cook Inlet (Bright, 1967). Many of Bright's (1967) conclusions conflict with what is known for other *Chionoecetes* species, especially regarding the terminal anecdysis in females and the duration of the reproductive cycle.

My study was directed at describing the reproductive biology of *C. bairdi* females in an attempt to provide information valuable to the management of the fishery and to address some of the questions created by conflicting results of previous research.

MATERIALS AND METHODS

I. Study Area

The specimens collected for this study came from the Prince William Sound fishery. As described previously, this effort is carried out inside Prince William Sound and in the adjacent Gulf of Alaska. About 90% of the catch comes from the outside area bounded by Hinchinbrook and Hawkins Islands on the north, Cape Cleare on the west, Cape St. Elias on the east, and Middleton Island to the south. Most of the region is 30 to 80 fathoms deep with several troughs as deep as 190 fathoms. The fishery is carried out primarily between 60 and 80 fathoms, with some of the larger boats fishing 150 to 160 fathoms.

The fishery inside Prince William Sound occurs in the southern sound south of Knowles Head and Naked Is. While this area has troughs as deep as 250 fathoms, the fishery is, again, mainly in the 50 to 80 fathom range.

II. Collection of Samples

Crabs were collected by two methods. All juveniles were obtained in otter trawl tows during August on the 1973 International Pacific Halibut Commission (IPHC) charter cruise aboard the M/V *Tordenskjold*. One hour trawls were made at IPHC stations 75B through 83D (Figure 1).

The trawl used was the standard large net employed each year by the IPHC. This net has a 94-foot foot rope and 71-foot head rope. The body is four inch mesh (stretch measure) #36 nylon cord; the cod end

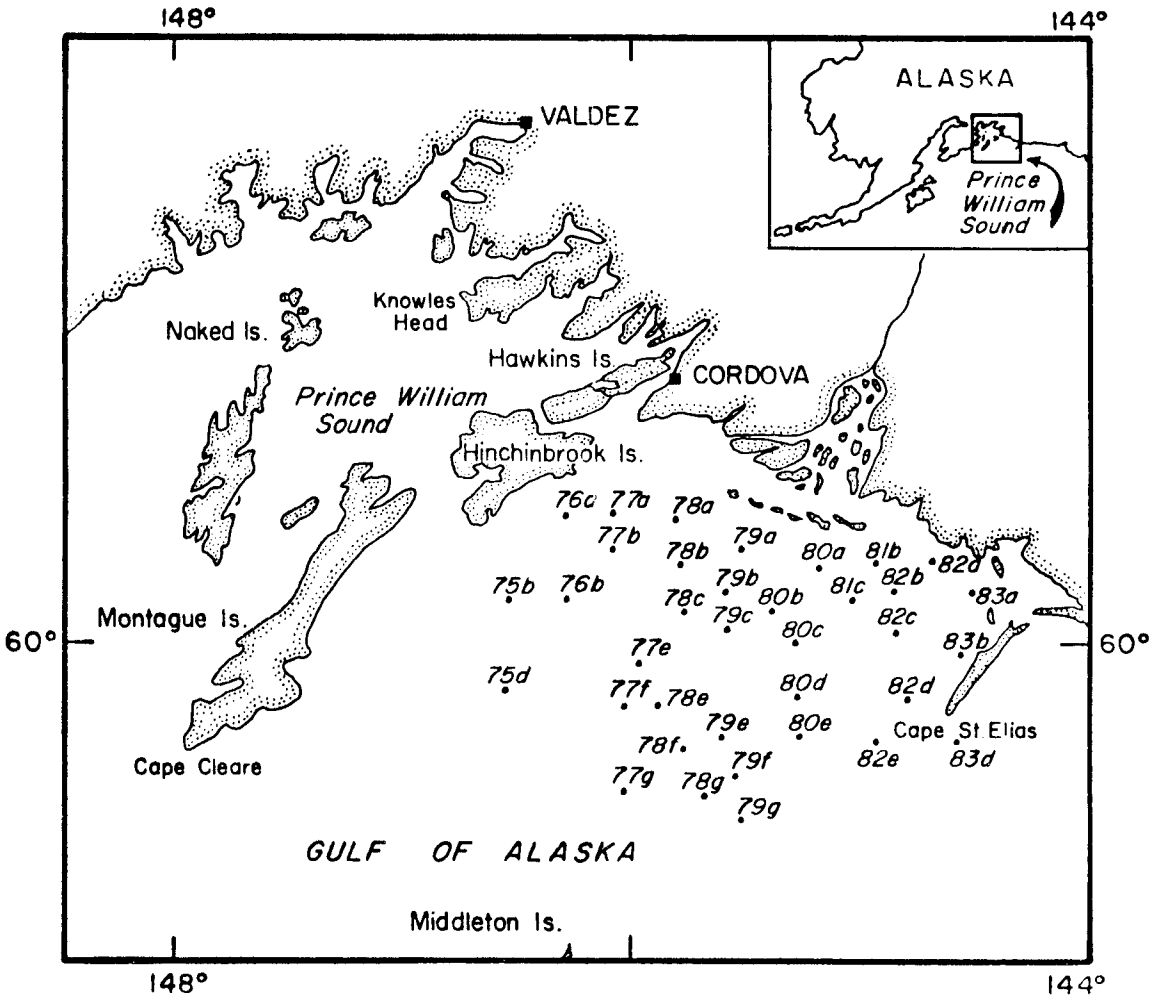

Figure 1. Prince William Sound fishing area and IPHC trawl stations 75B to 83D.

is three and one half inch mesh (stretch measure) #96 nylon cord.

Adult crab were collected in pots using chopped herring and halibut heads for bait. Collections were made in May and June, 1973 unless otherwise noted. Most of the adults were collected by the commercial fishery in top entry pyramid shaped pots (Brown, 1971). Mesh size on these pots varies, with a maximum of seven inches (stretch measure). During the fishing season, pots are only left in the water two to three days at most and are often picked up after a one or two day period. The bait seems to keep even the small adult female crabs in the pots for these short periods. Seven Japanese style long line pots (Zahn, 1970) lined with quarter or half inch mesh nylon net to retain all sizes of crab were fished on a limited basis. Crab were collected only from boats actively working their fishing gear. Fewer than 10% of the samples came from sets deeper than 70 fathoms.

III. Size Measurements

The size of a crab is expressed as the width of the carapace, (in millimeters) at its widest point (Powles, 1968). Mature crabs were measured to the nearest millimeter using a gauge modified after Watson and Wells (1970). Immature crabs were measured to the nearest one tenth millimeter except for sex ratio determinations where measurements were made to the nearest millimeter. A steel vernier caliper was used for these measurements.

IV. Sex and Stage of Maturity

Males and females are easily distinguished, even in the juvenile stage, by the much wider abdomen and presence of four pairs of pleopods in the female. Further, adult females my be distinguished by the egg clutch, and adult males by enlarged chelae. Females were classified as immature (pre-reproductive) or mature (reproductive or post-reproductive) based on the much wider abdomen of the mature female (Yoshida, 1941).

Immature (juvenile) females were classified into three stages of ovarian development: stage 1, the absence of the ovary; stage 2, the presence of an empty white ovary; or stage 3, the presence of an orange ovary. Mature (adult) females were further classified as: stage 4, ovary orange; or stage 5, ovary empty indicating atrophy or recent ovulation.

V. Egg Clutch Size

The egg clutch size was estimated from the relative amount of the volume between the abdomen and the sterna filled with eggs. Full clutches were those in which the eggs completely filled this space. The classifications three-fourths; one half; one fourth, and less than one fourth were relative to this.

VI. Shell Condition

The relative age of females after their terminal molt was recorded as three stages of shell condition. These were:

1) new shell —— a) color - orange and bright dorsally, white or pink ventrally

b) spines - sharp

c) shell - lacking epifauna and scratches

2) intermediate shell —— a) color - same as above but not shiny, ventral beginning to turn darker

b) spines - less sharp

c) shell - some scratches and epifauna

3) old shell —— a) color - brown on dorsal and ventral surfaces

b) spines - very dull

c) shell - heavily scratched and pitted particularly at base of legs, much epifauna

VII. Dry Weight

All weights reported in this study are of dried material. Drying was carried out in an oven at 60° C (Lovegrove, 1966) by placing material in pre-weighed aluminun pans. The duration of drying was initially determined by recording the weight at time intervals until a constant weight was obtained. Twelve to 18 hours were required for drying ovaries and small egg clutches, while large egg clutches were dried in two parts for this time period. Whole female bodies, less eggs and ovary, were dried for 72 hours.

Material was weighed on a Mettler H6 balance to the nearest 0.1 mg.

VIII. Egg Stage and Diameter

Egg development was classified as quoted by Boolootian *et al.* (1959) into the following ten categories:

1) No segmentation observable

2) Cleavage has taken place.

3) A yolk free (transparent) part becomes apparent. This stage coincides with the appearance of endoderm cells and the beginning of invagination.

4) A more distinct division into a yolk free and yolk containing part becomes clearly visible.

5) Eye pigment of embryo becomes visible.

6) Pigment bands of the embryo become visible.

7) Larva becomes strongly pigmented but still contains much yolk.

8) The yolk is reduced to two small separate patches.

9) Zoea larva becomes recognizable.

10) Free swimming zoea appears.

Egg diameters were measured to the nearest 0.01 mm with an ocular micrometer at 47 power. Eggs were frozen and thawed before measurement.

IX. Maturity Index

The maturity index (MI) is a measure of the weight of the ovaries relative to the size of the crab. Kon and Honma (1970) have defined the MI as

$$\frac{GW}{TW - EW - GW} \times 100$$

where GW is the ovary weight, TW is the total body weight, and EW is the weight of the egg mass. This formula is equivalent to

$$\frac{GW}{BW} \times 100$$

where BW is the body weight less the weight of the eggs and ovary as described in the dry weight section. All body weights were corrected for missing legs by adding the weight of the opposing leg. Crab missing both legs from one section were not considered.

X. Egg Number

Eggs were removed from the crab by scraping the masses away from the pleopods. Replicate estimates of egg number were obtained by comparing the weight of the egg mass to the weight of a two hundred egg subsample (Lagler, 1956). The mean of these two estimates was used in all calculations.

For purposes of examining statistical relationships, crabs were grouped into 10 mm size increments starting at 70 mm. The egg number-carapace width relationship was analyzed using a weighted linear regression with mean carapace width the independent variable (X), and mean egg number the dependent variable (Y). The weighting values (W) used in this regression analysis are

$$W = \frac{1}{S^2} \times 10^{-9}$$

where S^2 is the variance of the mean egg number for each size range.

RESULTS

I. Size at Maturity

There are several aspects of the sexual maturation process in female crabs. Highnam and Hill (1969) state that sexual differentiation progresses at sucessive molts, and the development of secondary sexual characteristics may not be complete until the gonads have matured. To fully describe the maturation process, it is necessary to know when the ovary first develops and when females become mature and capable of mating.

Forty-five immature females were examined to determine degree of ovarian development (Table 2). The ovary first appears (stage 2) in crab as small as 40 to 50 mm carapace width, though it does not appear in some crab as large as 60 to 70 mm wide. The ovary begins to mature (stage 3) in crabs as small as 67 mm but was found to be immature in one female of 80 mm. The 20 mm range for stage 2 females and 13 mm range for stage 3 females matches the variability in size at which females undergo the molt to maturity.

The smallest mature female collected was 71 mm compared with the largest immature at 93 mm (Figure 2). The size range between the smallest mature and largest immature females indicates that a range of almost 30 mm exist between the smallest and largest immature females ready to molt to maturity. The size at which 50% maturity occurs (Watson, 1969b) is very close to 80 mm carapace width (Figure 3).

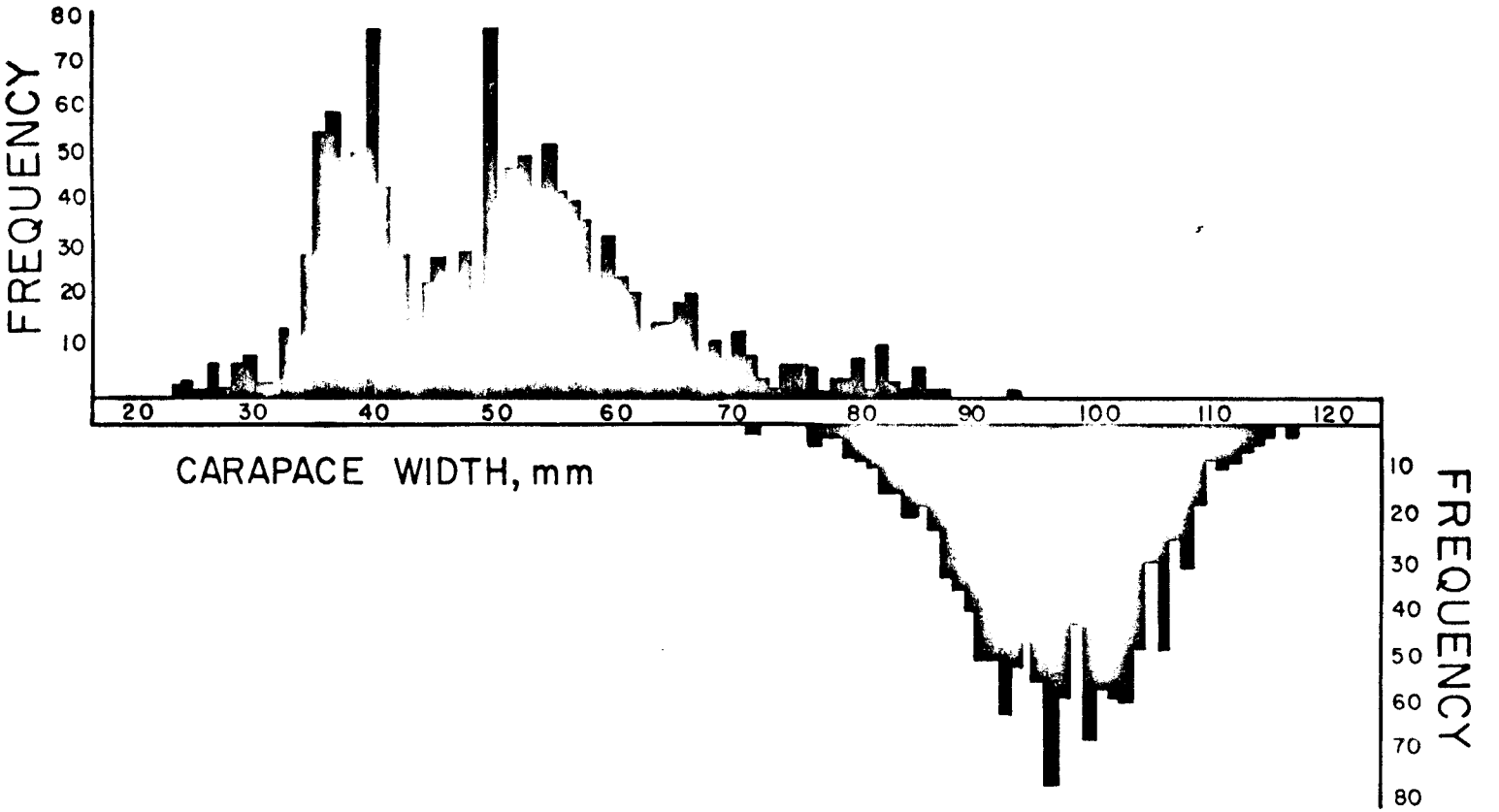

Figure 2. Size frequency distribution for 1380 immature female *C. bairdi* with average carapace width of 50 mm collected in IPHC trawl (upper histogram) and 1155 mature females with average carapace width of 96 mm collected in pots (lower histogram).

Table 2. Ovarian development in juveniles.

Size Range	Month	Number in Sample	Ovary Stage
20.0-29.9 mm	August	1	1
30.0-39.9	August	5	1
40.0-49.9	August	4	1
	May	2	2
50.0-59.9	May	2	2
60.0-69.9	August	10	4 @ 1 2 @ 2 4 @ 3
	May	5	2
70.0-79.9	August	8	3
80.0-89.9	August	7	3
	May	1	2

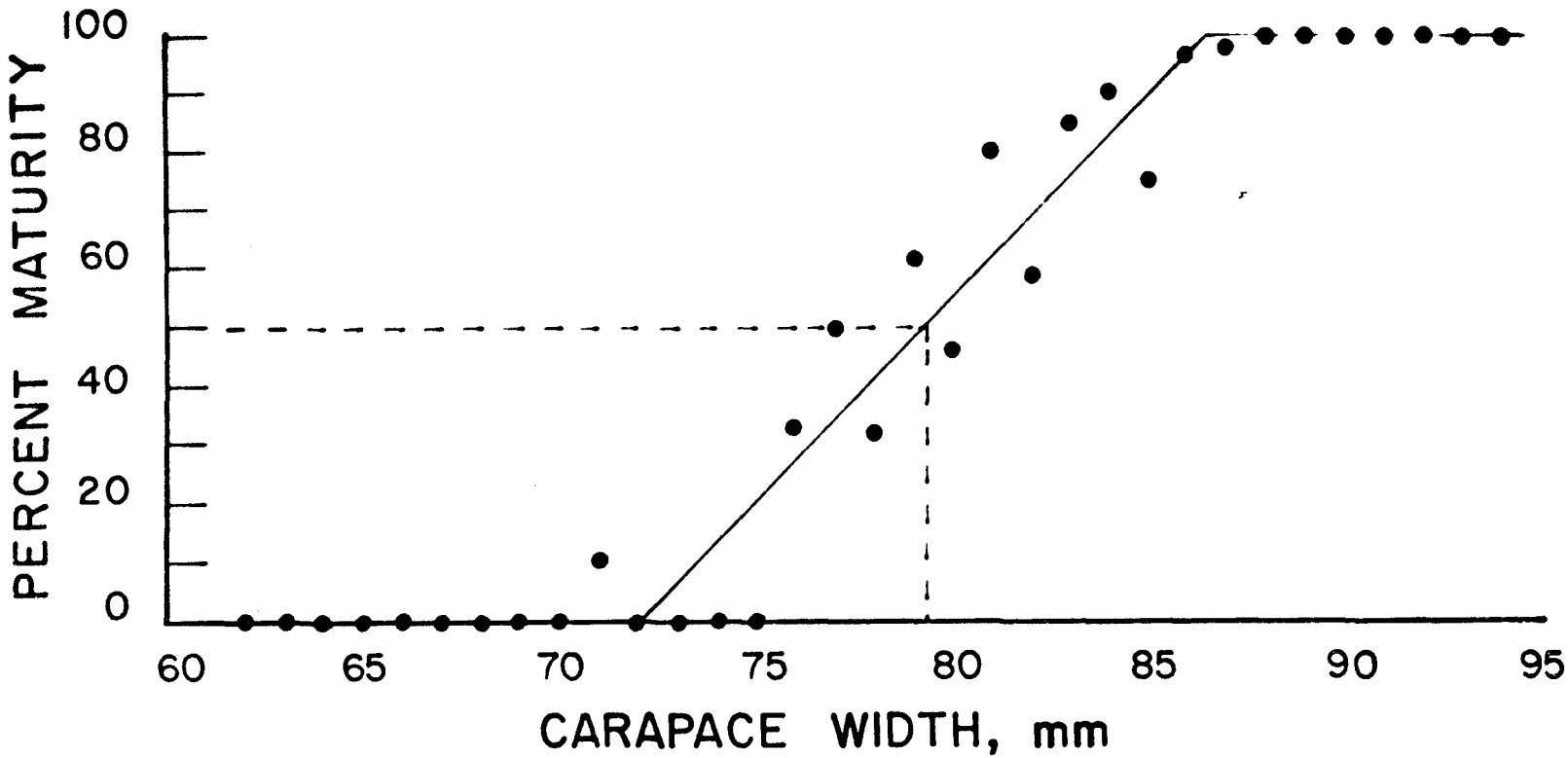

Figure 3. Percent maturity with carapace width in female *C. bairdi*.

II. Terminal Molt

Nearly all literature dealing with the family Majidae (Knudsen, 1964; Yoshida, 1971; Carlisle, 1957) supports the hypothesis that a terminal anecdysis occurs in females after the molt to full maturity.

Data presented by Bright (1967) and Edwards (1972) suggests that female *C. bairdi* continue to molt after the molt to maturity. If females do continue to molt past maturity, increased age will be related to increased size in adult animals.

Three parameters that should be related to age or continued molting were examined: 1) limb loss and regeneration; 2) egg clutch size; and 3) proportion of new shell crab. The frequency distributions for crab with varying numbers of lost or partially regenerated limbs (Figure 4) show a nearly identical size range for crab with zero or several missing limbs and those with partial regenerates. Less than five percent of the crabs were found to be regenerating limbs while 33% had lost no limbs and 65% had lost one to six limbs since last molting (Table 3). Crab regenerating more than one limb were very rare; they accounted for less than one percent of the sample. Partial or absent egg clutches were found in 12% of new shell crab and 33% of old shell crab (Table 4). All crab lacking an egg clutch were old shelled with a size range virtually identical to that for animals with full clutches (Figure 5). New shell crab made up only about four percent of the sample.

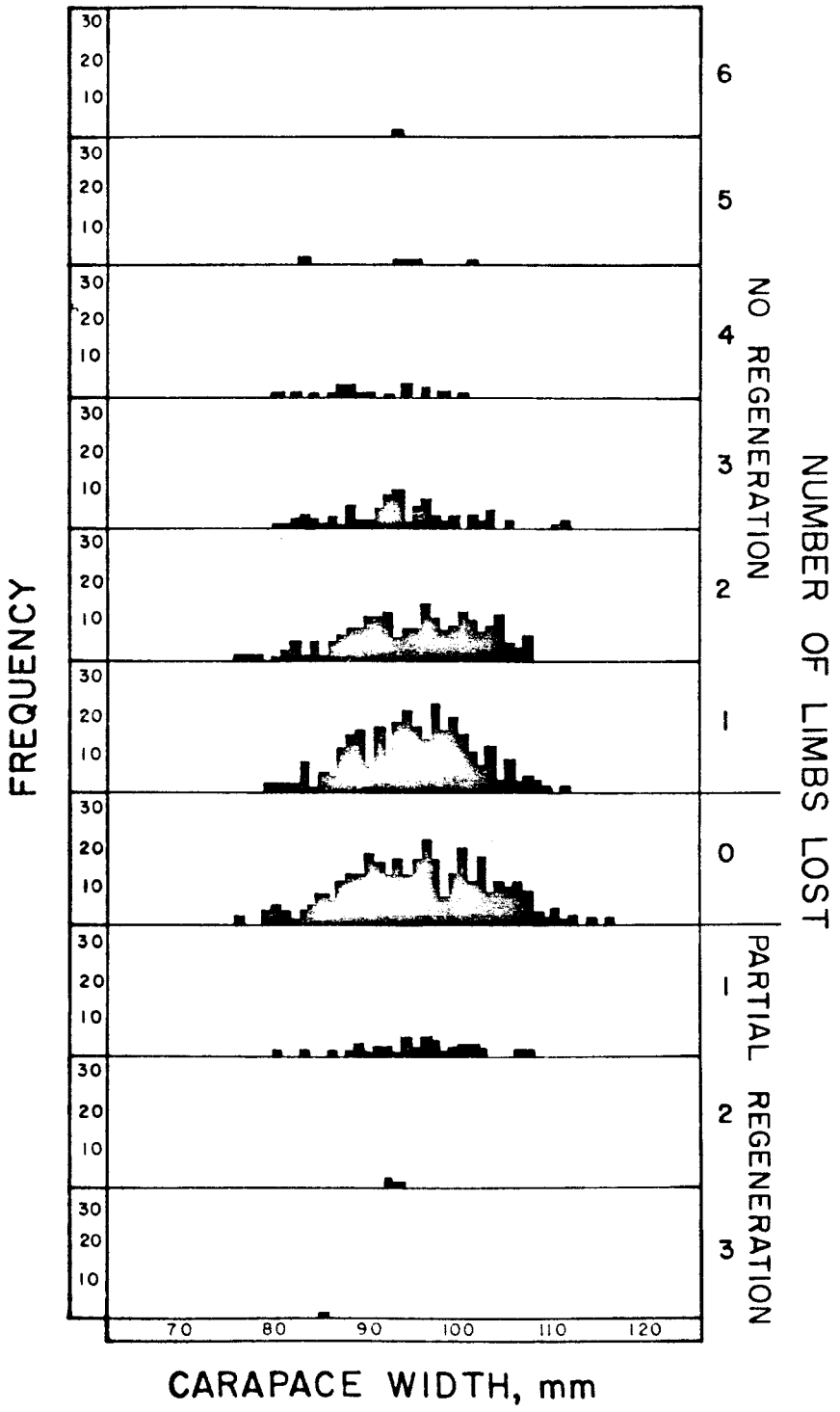

Figure 4. Size frequency distribution for female *C. bairdi* with lost and partially regenerated limbs.

Table 3. Limb loss and regeneration according to number of limbs missing.

Number of Legs	Number of Crabs				
	New Shell	Inter-mediate	Old Shell	Sub-total	Percent of Total
No legs missing					
0	20	2	301	323	32.3
Legs missing with no partial regeneration					
1	6	2	290	298	29.9
2	2	1	212	215	21.5
3	1	0	84	85	8.5
4	0	1	22	23	2.3
5	0	0	5	5	0.5
6	0	0	1	1	0.1
Legs partially regenerated					
1	6	1	35	42	4.2
2	0	0	5	5	0.5
3	1	0	0	1	0.1
Total	36	7	955	998	99.9
Percent of Total	3.6	0.7	95.7	100	

Table 4. Egg clutch size distribution by shell condition.

Number of Legs	Number of Crabs			Sub-total	Percent of Total
	New Shell	Inter-mediate	Old Shell		
Full	30	7	632	669	68
3/4	2	0	66	68	7
1/2	2	0	56	58	6
1/4	0	0	36	36	4
Less than 1/4	0	0	65	65	7
Absent	0	0	91	91	9
Total	34	7	946	987	101
Percent of Total	3	1	96	100	

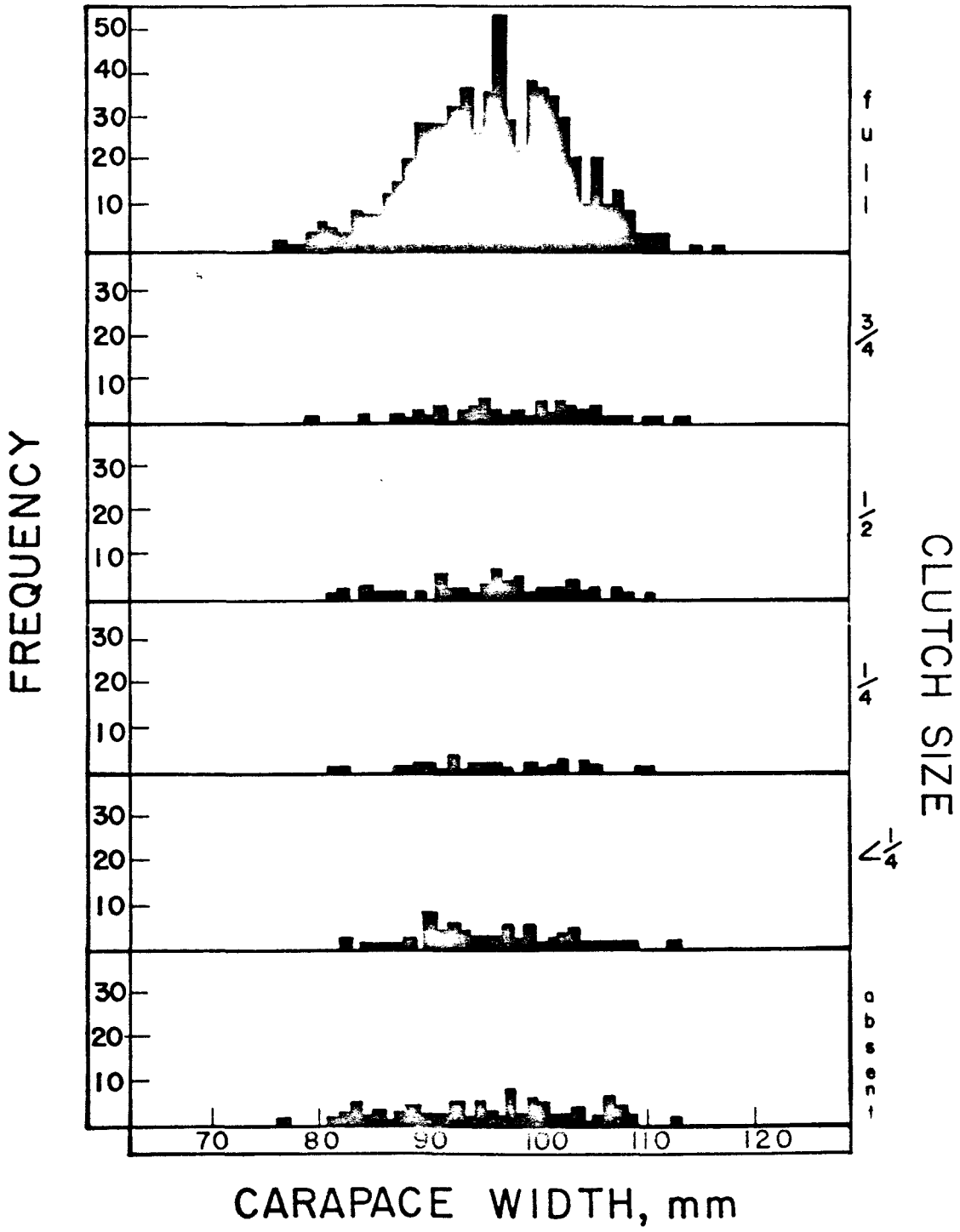

Figure 5. Size frequency distribution for female *C. bairdi* with varying sizes of egg clutch.

III. Reproductive Cycle

Several parameters were examined as a means of describing the reproductive cycle in *C. bairdi*. These were egg development, ovary development as measured by maturity index (MI), and the relationship between egg stage and shell type at a certain time of the year.

The results of this portion of the study indicate a one year cycle of development for eggs and ovaries (Figures 6 and 7) beginning in late April or early May with egg extrusion. The eggs are a bright orange color immediately after extrusion turning to brown before hatching. The eggs develop to stage 4 within several weeks of extrusion and remain in this condition until winter, when the eye spot forms (stage 5). In mid-April the zoea is recognizable (stage 9) as the eggs approach hatching. The diameter of the eggs just after extrusion averaged 0.53 mm (95% confidence interval, ± .004 mm). Just before hatching the eggs had increased in size to an average diameter of 0.66 ± .01 mm. This difference in diameter is statistically significant ($\alpha = .05$). A similar increase in weight does not appear to occur. The weight of an individual stage 3 or 4 egg in mid-May averaged $3.93 \times 10^{-5} \pm .14 \times 10^{-5}$ grams. This did not change significantly with development to stage 9 eggs. The ovary is empty after extrusion, with only a white ovarian wall visible, and the MI is 0.3. The MI increases during the year (Figure 7) until it reaches 14 in mid-April. At this time females are again ready to extrude the new clutch of eggs.

Primiparous spawners follow a slightly different pattern than outlined above for multiparous spawners. Rather than extruding eggs in

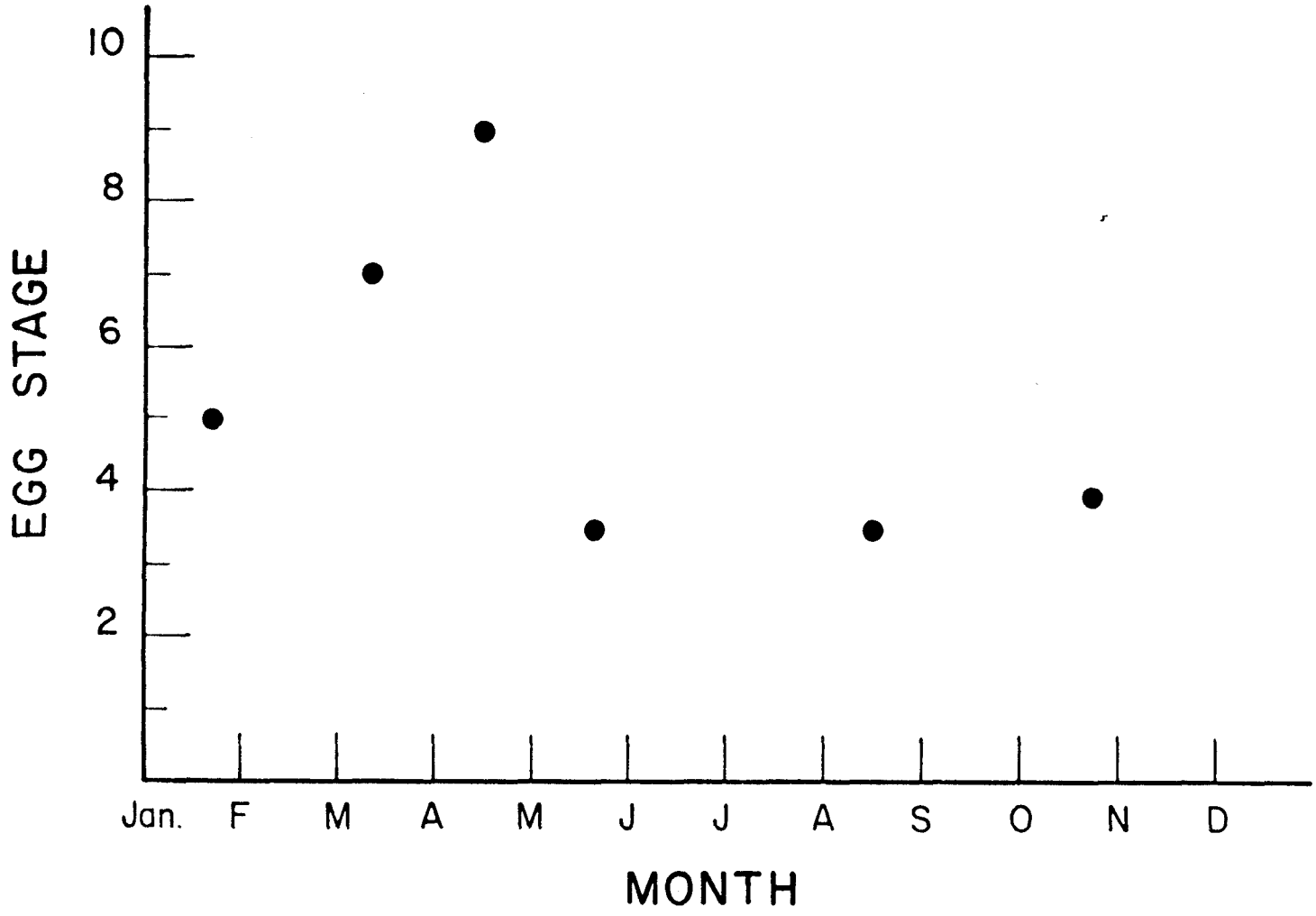

Figure 6. Egg development with season for multiparous spawners.

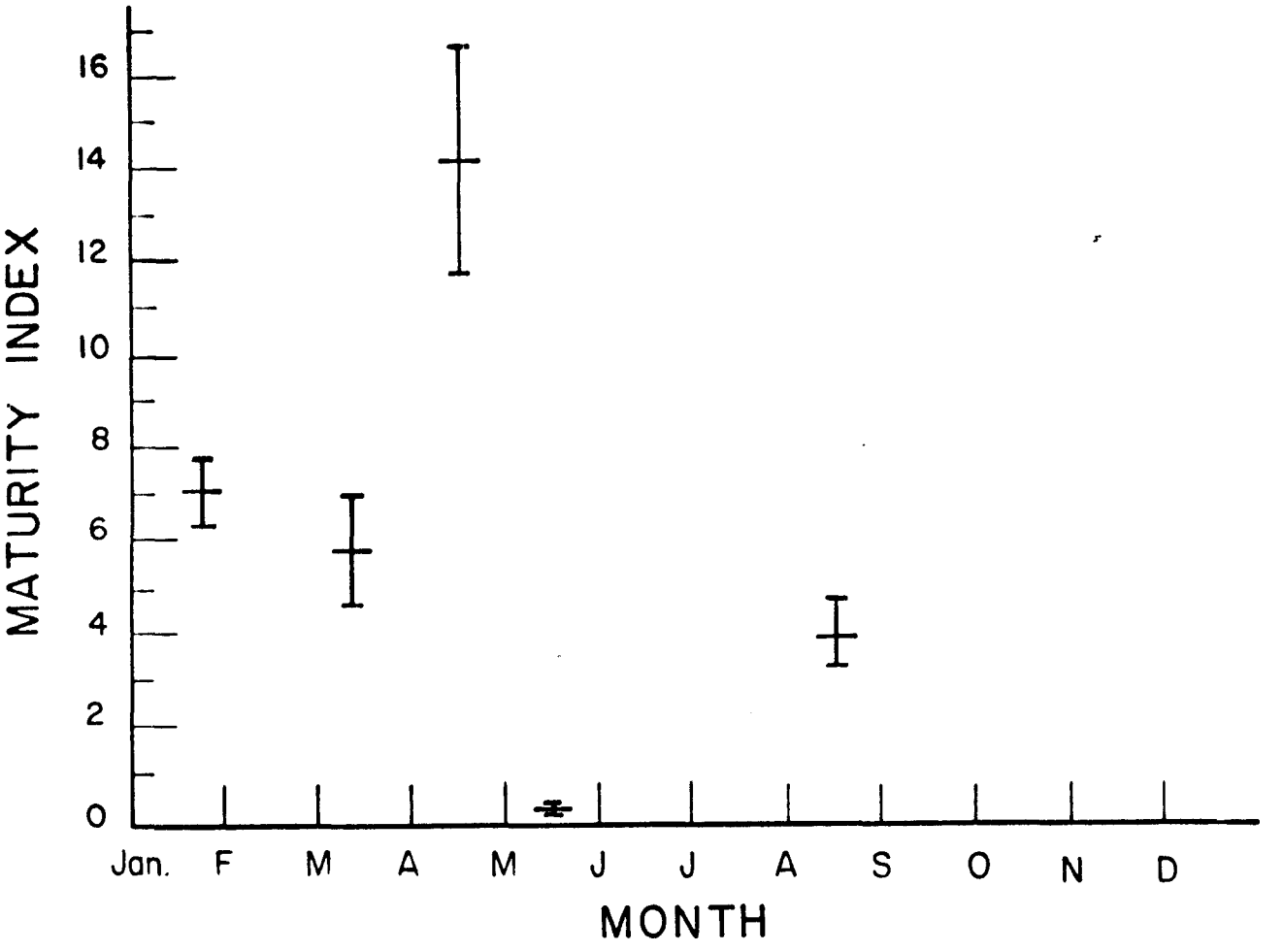

Figure 7. Maturity index with season for multiparous spawners; means and 95% confidence intervals depicted.

late April or early May, these animals molt to maturity, mate, and extrude their eggs earlier in the year. All the soft shell primiparous crab collected in mid-April carried stage 2 eggs when hard shell multiparous spawners carried stage 9 eggs.

IV. Percent of Females Bearing Eggs

The percent of females bearing eggs each year is probably related to the proportion of successful matings. Watson (1970, 1972) has shown that female snow crab may mate only once, at the time of their molt to maturity. For this reason, in my study, all females were separated according to shell condition into two groups, new and intermediate shells versus old shells. The new shell females would be those recently mated, the old shell females those presumably mated long before. It was necessary to separate the two groups to determine the proportion of barren females due to old age and to gain some idea of current mating success.

All new and intermediate shell crab were ovigerous while 11% of the old shell crab were non-ovigerous (Table 5). Considering the entire sample of 1034 crabs, 90% were ovigerous and 10% non-ovigerous. Ovaries of 61 out of the 109 non-ovigerous crabs were examined. 64% of these had a white stage 5 ovary, the remainder were animals with orange ovary that had not yet extruded the egg clutch. Based on 109 non-ovigerous females, approximately seven percent of the total were crabs with old shell, white ovary and no egg clutch, while four percent were non-ovigerous crabs who had not yet ovulated.

Table 5. Percent of ovigerous females by shell condition.

Category	Number Examined	Percent of Subtotal	Percent of Total
Old shell			
Ovigerous	877	89	85
Non-ovigerous	109	11	10
	986		
New and intermediate shell			
Ovigerous	48	100	5
Non-ovigerous	0	0	0
	48		
Non-ovigerous females examined for ovary condition			
Orange ovary (stage 4)	22	36	4
White ovary (stage 5)	39	64	
	61		
Total	1034		100

Note: Non-ovigerous females examined for ovary condition are included in the total as part of the 109 non-ovigerous females.

V. Egg Number

In previous research describing egg number in *C. opilio*, Brunel (1962) found a significant change in egg abundance between the times of extrusion and hatching. Egg number estimates for *C. bairdi* were, therefore, obtained for both stage 4 eggs collected during the summer and stage 9 eggs collected in the spring.

Mean carapace width, egg number, abundance range, and weighting value for each size interval and season were determined (Table 6). There is tremendous variation in egg abundance at both times of the year, with a summer range of 34,000 to 317,000 eggs per female and a spring range of 24,000 to 318,000 eggs per female. Crab of the same size will often have differences in egg number of 200,000.

The resulting weighted linear relationships for mean egg number versus mean carapace width (from Table 6) for the summer and spring groups are $Y = 4610.10(X) - 275{,}833$ and $Y = 2347.53(X) - 95{,}125$ respectively (Figure 8). A covariance analysis (Table 7) was used to test the null hypotheses of no difference between those two lines. The resulting F-ratio of 71.3 indicates we cannot accept this null hypothesis.

The decrease in egg number within groups showed a large range; 80-89 mm, seven percent; 90-99 mm, 23%; 100-109 mm, 20%; 109-119, 37%. The overall average egg number decreased significantly ($\alpha = .05$) by 21% from 169,000 during the summer of 133,000 in spring. Several animals were found among egg masses during the procedure for preparation for counting: *Carcinonemertes* sp., an unidentified gammarid amphipod, and a polychaete, *Harmothoe imbricata*.

Table 6. Mean estimated egg number by size range and season.

Size Range	Sample Size	Mean Width	Egg Number				
			Low	High	Mean	Variance About Mean	Weighting Value (W)
SUMMER							
70-79	4	78	72,000	100,000	85,000	5.76×10^8	1.736
80-89	17	86	64,000	228,000	119,000	1.52×10^9	.657
90-99	24	95	34,000	244,000	154,000	3.25×10^9	.308
100-109	42	104	42,000	317,000	201,000	5.04×10^9	.198
110-119	2	112	222,000	262,000	242,000	8.00×10^8	1.250
overall	89	97	34,000	317,000	169,000	5.04×10^9	--
SPRING							
70-79	0	—	—	—	—	—	--
80-89	24	86	34,000	172,000	111,000	1.44×10^9	.693
90-99	28	95	24,000	173,000	119,000	1.30×10^9	.772
100-109	30	104	39,000	244,000	160,000	2.12×10^9	.473
110-119	7	111	40,000	318,000	153,000	9.80×10^9	.102
overall	89	97	24,000	318,000	133,000	2.64×10^9	—

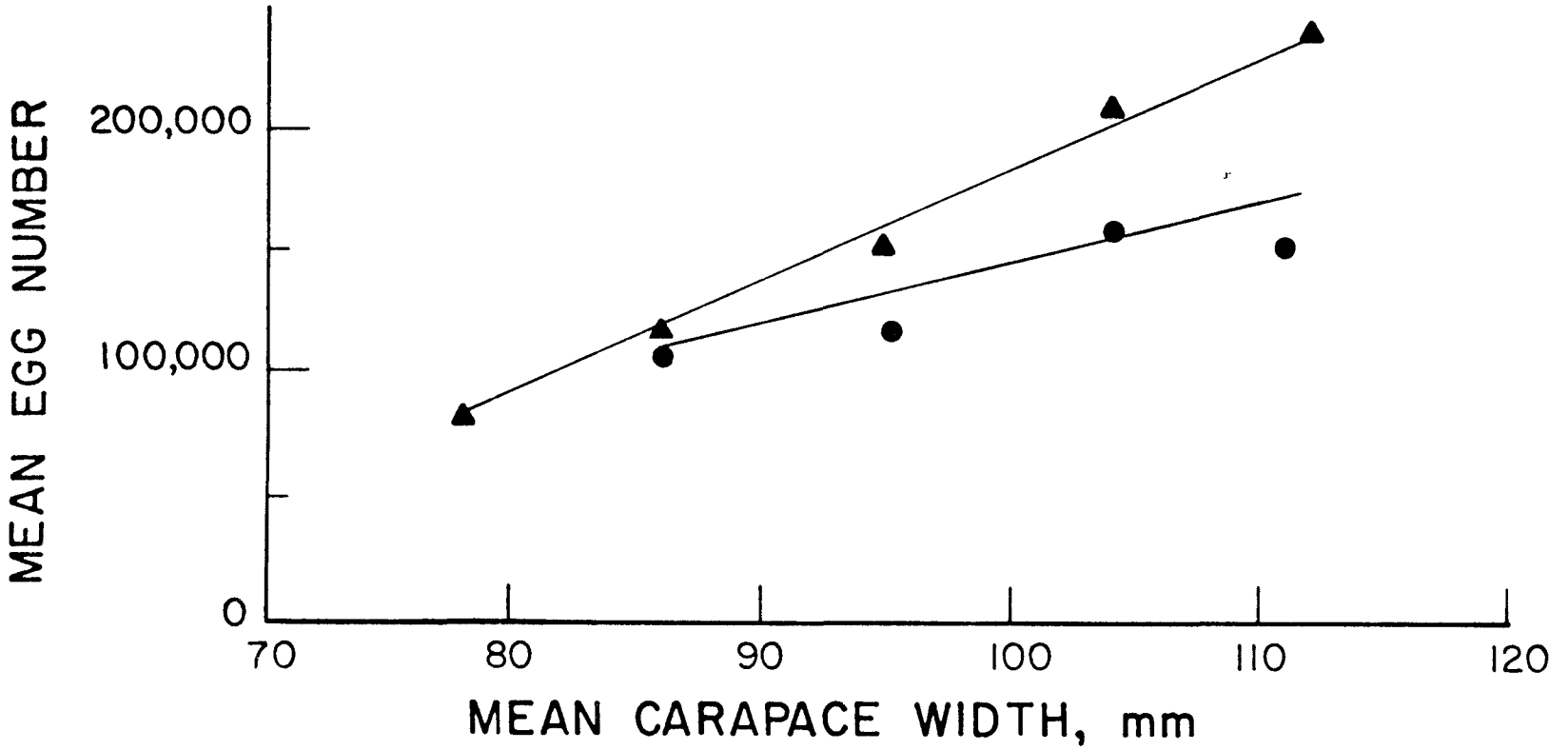

Figure 8. Weighted linear regression lines for summer (Δ) and spring (o) egg number - carapace width relationship. Summer; Y = 4610.10 (X) - 275, 833 Spring; Y - 2347.53 (X) - 95, 125.

Table 7. Analysis of covariance table for egg number - carapace width regression.

Source of Variation	Sum of Squares	Degrees of Freedom	Sum of Squares / D.F.	F
Between Lines	$S_T - S_E$	2	19,766,600,334	71.3
Within Lines	S_E	5	633,014,866	
About a Single Line (Total)	S_T	7	20,459,615,200	

VI. Sex Ratio

The ability to detect changes in the sex ratio of population may be a very important management tool in single sex fisheries (Kingsbury and James, 1971), such as snow crab, king crab and pandalid shrimp.

The ability to detect changes in the sex ratio depends on a knowledge of the sex ratio in the unfished population. There are sufficient examples of skewed sex ratios (Hamilton, 1967) particularly in the Crustacea (Wenner, 1972; Gray and Powell, 1963; Pererya, 1967) to prevent the *a priori* assumption of 1:1 sex ratio in unfished snow crab populations.

Juvenile

The overall sex ratio for juveniles was approximately .92 females per male (13,171 females, 15,345 males). This ratio was found to be significantly different from 1:1 using a binomial test ($p < .005$).

There was a large fluctuation in sex ratio between IPHC stations (Appendix D) with females in greatest abundance at some stations and males more numerous at others. A chi-square test including all stations where the expected number of each sex was greater than five yielded a X^2_{29} of 72.5. Thus, the hypothesis of a 1:1 sex ratio at each station is rejected ($p < .005$).

The large fluctuation in percent of females in the trawl samples was significantly correlated to average size of females in that sample, and not to depth or number of animals in the sample (Table 8). This

Table 8. Correlation between percent female and other parameters.

	Regression Line	r	Critical r $\alpha = .05$
Depth	Y = 49.93 - .05(X)	0.072	0.344
Total abundance	Y = 1024 - 2.02(X)	0.092	0.340
Average size of female	Y = 28.18 + .41(X)	0.426	0.340

correlation shows an increasing percentage of females with an increasing average female size.

Adult

The adult sex ratio in the trawl samples was extremely skewed. Out of a total of 421 adults only 66 (16%) were females. Since inshore areas inhabited almost solely by female crabs are known to exist (Mr. Gerald Thorne, personal communication) it is evident that the adult sexes are spatially segregated.

For this reason it is difficult to accurately estimate the adult sex ratio. The regression equation for percent females versus average size of female (Table 8) can be used to predict the sex ratio at the average adult female size of 96 mm (Figure 2). The predicted sex ratio is 2.1 females per male or 68% females.

DISCUSSION

I. Size at Maturity

Consistent with what is known generally for the Crustacea (Highnam and Hill, 1969), female *C. bairdi* go through several stages in the process of sexual maturation. The smallest juvenile females are distinguishable from males by the wider abdomen, four pairs of pleopods, and vulvae. These structures along with the ovary which forms later, develop in the absence of androgenic hormones. The fully developed ovary appears when females are between 45 and 80 mm carapace width while the final molt occurs in crab between 65 and 95 mm. Assuming that ovary development and full maturation are both related to size in a similar way, the ovary appears while the crab still has 20 to 30 mm to grow. Donaldson's (1974) growth per molt data suggest this would take two or three molts.

Changes taking place at the molt to maturity which prepare the female for bearing eggs are evidently controlled by ovarian hormones (Highnam and Hill, 1969). Since all juveniles found with a stage 3 ovary were large enough to enter the observed size range for adults in one molt, it is likely that the molt to maturity is keyed to the maturation of the ovary rather than a specific age or number of molts. The next molt after the maturation of the ovary becomes the molt to maturity.

The size at 50% maturity, 80 mm, represents the carapace width at which there are an equal number of adult and juvenile animals.

Such a value has been used (Watson, 1969b) to describe the size at which females molt to maturity when that size is quite variable as in snow crab. This value will be affected by the ability of the gear to sample large juveniles and small adults since all juveniles were collected in a small mesh trawl the large juveniles would be retained. The commercial pots were found to retain the adult animals in the same range as the Japanese long line pots lined with small mesh netting.

Approximately 11 to 12 (Donaldson, 1974) molts would occur before a female *C. bairdi* reached maturity compared with 11 molts for female *C. opilio* to reach maturity at about 50 mm (Kon *et al.*, 1968). The ovarian maturation process is presumably superimposed on a continuous molt cycle such that the size and age at maturity are a result of the combination of growth per molt, frequency of molting, and timing of gonad maturation. It is likely that a combination of the natural variation in these parameters creates much of the 71 mm to 116 mm size range of adult females.

II. The Terminal Molt

The presence of a terminal molt at maturity in females of the family Majidae has been fairly well established (Knudsen, 1964; Carlisle, 1957; Skinner and Graham, 1972; Highnam and Hill, 1969). Most research on *Chionoecetes* has supported this finding (Yoshida, 1941; Kato *et al.*, 1956). For several reasons, however, it was necessary to study the possibility of continued molting in *C. bairdi*. Bright (1967) recorded females as large as 157 mm which is 30 mm larger than

any other recorded female of the species (Brown, 1971). Adult females held in live tanks molted, leading Bright to believe that female *C. bairdi* commonly molt two to three times after maturity. Edwards (1972) found that adult female *C. bairdi* in the Bering Sea had a limb regeneration rate greater than that for adult males and equal to that for juvenile crab. Regeneration is limited to development of the limb bud until the next molt occurs since growth of this bud is stimulated by hormones from the Y-organ released prior to molting (Lockwood, 1967). A high percentage of crab with regenerated limbs would suggest that molting continued in mature crabs or that there was a large amount of limb loss among juveniles that was carried over as partial regeneration in adults.

Under the assumption that molting commonly occurs in adult female *C. bairdi*, one would expect to see a high percentage of new shell females particularly among small adults, a tendency toward partial or absent egg clutches in larger (hence older) animals due to an atrophied and a high rate of regeneration. None of these conditions were found in the population studied. New shell crabs accounted for less than five percent of the total sample. The large proportion of old shell crab in the 70 to 90 mm carapace width range indicates females do not grow out of this very small size range. Partially regenerated limbs were found on only five percent of the sample. Analysis of size frequency data shows that size is not related to partial or absent egg clutches, or increased limb loss or regeneration. Analysis of similar data from Kodiak Is. (W. E. Donaldson, unpublished data) shows that there is no

shift in size with increasing shell age or increasing incidence of partial or absent egg clutches. Nearly 30% of the Kodiak area females sampled were new shell or recently molted to maturity. The difference in percent of new shell females between Kodiak and Prince William Sound may be related to spatial segregation of females by age. There appears to be no growth after the molt to maturity in either Prince William Sound or Kodiak.

Edwards (1972) found that 59% of the adult female *C. bairdi* he collected in the Bering Sea had partially regenerated limbs while only 39% were missing limbs without partial regeneration. This is likely due to some factor causing very high limb loss in juveniles. Lost limbs would be carried partially regenerated into the adult phase.

Bright (1967) and Ito and Kobayshi (1967) observed adult female snow crabs (*C. bairdi* and *C. opilio* respectively) molting. Such observations prove that some females may retain the ability to molt after maturity. Bright's (1967) conclusion that female *C. bairdi* commonly molt two or three times after maturity should be rejected. Some female *C. bairdi* grow as much as 30% during the molt to maturity (Donaldson, 1974). Such a growth increment, even assuming every female undergoes a terminal molt at maturity, is sufficient to explain the entire adult female size range observed in the Cordova area.

It is not known what process would cause a few mature females to continue molting. Carlisle (1957) has found that the Y-organ which produces the molt stimulating hormone atrophies after maturity in *Maia squinado*. Molting would presumably continue if atrophication did not

occur. Skinner and Graham (1972) have shown limb loss to be a stimulus to ecdysis in some brachyurans. Their experiments with both limb loss and eye stalk extirpation failed to produce molting in the female majid *Libinia emarginata*. Limb loss does not appear to be related to molting in adult female snow crabs either. Of six new shell females over 106 mm carapace width five were missing zero or one limb and none had partially regenerated limbs. If these were crab that had molted after maturity it may be that their healthier condition due to having all legs present was related to the extra molt. Females molted when kept in pens and fed by Bright (1967) indicating again that environmental factors and overall health may be related to the terminal anecdysis.

III. Reproductive Cycle

The yearly reproductive cycle described is of similar duration to that described for other snow crab. Rather than extruding eggs in late April and early May, *C. opilio* and *C. tanneri* ovulate in March and April (Ito, 1963, 1967; Watson, 1970; Pererya, 1967).

All the cycles described for other snow crabs differ markedly from Bright's (1967) conclusion that the ova develop in less than six months and eggs develop in six to seven months. If Bright's (1967) development rates are part of a yearly cycle, most females would be non-ovigerous and have a stage 5 ovary for five to six months each year. Such an observation is counter to all current information on snow crabs and must be considered an error.

Females spawning for the first time (primiparous) go through their molt to maturity and mating in the winter or early spring as opposed to *C. opilio* where these events occur in the late summer or fall (Ito, 1967; Kon and Honma, 1970). Hard newshell females collected in mid-April were carrying eggs at the same developmental stages as old shell crab. The primiparous spawners apparently hatch their eggs at the same time as other females. Colder water temperatures in the late winter and early spring could prolong the initial stages of egg development. Subsequent clutches of eggs are extruded by hard shell females. This is contrary to findings for king and dungeness crab (Powell and Nickerson, 1965; Snow and Nielson, 1966) though common (Hartnoll, 1969) in the Majidae due to the terminal molt.

It is not known whether or not females must mate prior to the extrusion of each egg clutch as happens in most crabs. Watson (1972) observed unmated female *C. opilio* produce fertile egg clutches from sperm stored in the spermathecae. He reports (Watson, 1970) that similar observations have been made for *C. bairdi* and that mating by adult females has not been observed. It was his conclusion (Watson, 1972) that all subsequent egg clutches are fertilized from sperm stored from a single mating after the molt to maturity. Cheung (1968) states that female stone crab, *Menippe mercenaria* can produce more than 10 viable egg clutches in one intermolt period fertilized by sperm stored in the spermathecae.

Ryan (1966) and Kittredge and Takahashi (1972) have described a pheromone which stimulates mating behavior in male brachyurans. This

pheromone is a dilute solution of the crustacean molting hormone which is released from the body along with the urine. In adult females of the family Majidae the Y-organ atrophies halting production of the molting hormone. In order for these females to continue mating some alternate mechanism for stimulating and coordinating mating would have to exist.

The fertilization process has been described for another majid crab, *Libinia emarginata* (Hinsch, 1971). Spermatophores transferred during mating are stored in the spermathecae (Hartnoll, 1968) where the sperm may come in contact with the eggs. During ovulation many of the non-motile sperm attach to each ova as it passes through the ova ducts and out the vulvae. Fertilization is completed outside the body of the crab. Egg coatings and the funiculus which attached the egg to the pleopods form after fertilization as a product of the developing egg (Hinsch, 1972; Cheung, 1966).

IV. Percent of Females Bearing Eggs

The percent of females bearing eggs may decrease due to a reduction in mating successes through over fishing (McMullen and Yoshihara, 1969). Also certain environmental factors such as temperature and food supply have been shown to cause changes in percent of ovigerous females in the crayfish, *Astacus astacus* (Abrahamsson, 1973). In snow crabs, whose environment is relatively constant compared to freshwater crayfish, changing environmental conditions are not a probable cause for decreases in the percent of ovigerous females but may explain differ-

ences in percent of ovigerous females between areas. In an intense fishery, such as that for snow crab, over fishing should be considered the most likely though not exclusive reason for declining numbers of egg bearing females.

In the situation where female crabs only mate once, the percent of new shell crabs bearing eggs will be related to the proportion of successful matings that year and the percent of ovigerous old shell crabs will provide an indication of mating success in previous years. When sampling is carried out soon after ovulation, as mine was, it is very difficult to determine which old shell crabs are barren due to old age, or due to ovulation without egg attachment. The 11% of old shell crabs without eggs is made up of crab from these two categories so it is much higher than the true value for non-ovigerous females within their reproductive years. Crabs collected during August through mid-April with orange ovary and no egg clutch could be considered barren females due to non-fertilization or abnormal fertilization such that egg attachment did not occur. The important value from a management standpoint is the percent of ovigerous new shell females. The fact that 100% of the 50 new shell females sampled were ovigerous indicates that under normal conditions the percent of ovigerous new shell females is quite high and probably approaches 100%. Fertile egg clutches were found in 98% of 1855 old and new shell females sampled near Kodiak Is. in 1974, (W. E. Donaldson, unpublished data). Significant changes in these percentages of egg bearing females should be a sign that stocks may be over exploited or under environmental stress.

V. Egg Number

Egg number estimates for all snow crab species studied show a large variation. The range of 24,000 to 318,000 eggs per female *C. bairdi* compares with 20,000 to 140,000 and 6,000 to 130,000 eggs per female *C. opilio* in Canada (Watson, 1969) and Japan (Ito, 1963) respectively. The large egg number variation exists between females of both varying and similar sizes. A natural size egg number relationship, large variation in full clutch size, and decrease in clutch size in very old animals probably accounts for much of the variation.

Each egg number estimate was the mean of two replicates. These estimates were performed on dried eggs in order to reduce the variability in weight caused by water within and on the eggs. The two estimates were generally within five percent of each other. The subsamples were collected at random after tests indicated insignificant differences in egg size with position in the egg mass.

A weighted linear regression was used to describe the egg number-carapace width relationship in order to compensate for the differing variance about the mean egg number for each 10 mm size interval. Groups with lower variance about the mean carried more weight in the regression. These groups were used to increase the number of crab in the sample for each size class. Covariance analysis was used to test for changes in the egg-number carapace width relationship over the entire size range rather than simply between individual groups. The significant changes in the linear relationship and overall average egg

number between egg extrusion and hatching were expected. Brunel (1962) found a 50% decrease in egg number of *C. opilio* over a similar time period, while Kon (1974) discovered egg loss as high as 45% in *C. opilio* from Japan and a pattern of increased egg loss in larger crabs.

The decrease in egg number is attributed to several sources; 1) death and disintegration of abnormal embryos, 2) predation, 3) natural variation in egg number between crab. Several animals found in the egg masses apparently devour eggs. One, a nemertean worm identified as *Carcinonemertes* sp. by George Mueller (Marine Sorting Center, Univ. of Alaska) is known (Coe, 1902; Humes, 1942) to infest female crab gills while the worm is immature; and to move into the egg mass and devour eggs after the worm has become sexually mature. Members of this genus have also been found in another majid crab, *Epialtus productus*. An unidentified gammarid amphipod was found occassionally on the edge of the egg mass, as many as 19 at one time, surrounded by a large indentation in the mass apparently caused by devoured eggs. A polychaete, *Harmothoe imbricata* was also found in an egg mass but no reference could be found in the literature to its possible predation of eggs. The summer and spring samples were kept as similar as possible with respect to size and number of crab. Unfortunately, in the 110-119 mm wand 70-79 mm groups it was not possible to match the two samples very closely which may have had an effect on the resultant difference in egg number.

Using the average egg number for each size group and the number

of crabs in each group according to the size-frequency distribution in Figure 2, the 1155 crabs sampled would produce approximately 150 million eggs in one year. The percentage of this number produced by each size group is: 70-79 mm, 0.8%, 80-89 mm, 18%, 90-99 mm, 43%, 100-109 mm, 38%, 110-119 mm, 3%. The crab less than 79 mm and over 109 mm in carapace width, though interesting from a physiological point of view, play an insignificant part in reproduction.

VI. Sex ratio

The overall sex ratio among *C. bairdi* (.92 females per male) appears to be very close to, but significantly different from 1:1. This may be due to having subsampled the largest trawl catches for determination of sex ratio. The linear relationship between percent of females and average size of females gives a predicted value of 49% females at the average size of 50 mm. The juvenile sex ratio should, therefore, be quite close to 1:1. There is no reason to feel that males were collected more effectively by the trawl. The segregation of juveniles by size causes the fluctuation in sex ratio between stations. The relationship between size and sex ratio was suggested by Wenner's (1972) finding that the sex ratio in most marine crustacea changes with size due to differential mortality and growth. Although insufficient data is present for *C. bairdi* less than 30 mm carapace width, the sex ratio-size pattern appears to be similar to Wenner's (1972) "anomalous" pattern. A 1:1 sex ratio at birth is followed by differential mortality and growth causing first one sex and the other

to be most abundant. Such a pattern has been found in brachyurans, anomurans, amphipods, and harpacticoid copepods. A determination of the neonate and small juvenile sex ratio would add necessary data to determine how well *C. bairdi* fits Wenner's pattern.

The predicted imbalance in the adult sex ratio (2.1 females per male) is very similar to the 2.5 females per male found on the breeding grounds in *C. tanneri* (Pererya, 1967). Using the size-sex ratio relationship for juveniles to predict adult sex ratio will give an inaccurate estimate unless mortality is similar in large juveniles and adults in both sexes. Since the prediction is made for the average adult female size of 96 mm, it is not affected by the differential growth rate between adult males and females. The advantage of this prediction is that it should represent the sex ratio in the unfished population. Any empirical sex ratio derived now would have to take into account the removal of males by the fishery to give an estimate of the sex ratio before intense fishing began.

Pererya (1967) considered the possibility that snow crabs are polygamous due to the imbalance in the sex ratio. Under the assumption that females mate only once, the sex ratio for mating purposes will not be the same as the overall sex ratio. Males might mate year after year but it is unknown how many times they would mate in one year. The population of mating females would be quite small based on the percentage of new shell crab collected. Possibly not all males would mate in any one year. If females do mate each year, then males may, as the sex ratio indicates, mate with more than one female each year.

FUTURE STUDIES

The Alaskan snow crab fishery is still a developing fishery. Many questions remain unanswered with regard to its management. Study of the reproductive biology of female snow crabs was undertaken because it could provide useful information for management of the fishery. Full utilization of reproductive biology as a management tool requires that certain additional information be collected. Monitoring programs are necessary in each of the major fishery areas to detect changes in sex ratio, egg number, and percent of ovigerous females. Changes in these parameters will become more valuable as indicators of stock condition when they can be correlated to fishing intensity and subsequent changes in the catch per unit of effort and estimated abundance of snow crabs. It is necessary to know where the first indicators of over fishing appear and how they are related temporally, quantitatively, and spatially to other indications of over fishing.

To determine the seriousness of changes in the reproductive capability of snow crabs it is necessary to know the exact relationship between number and size of male crabs and production of eggs. To determine this relationship studies should be conducted to find out the number of times a female may mate; how often she mates, if more than once; how many females are fertilized by each male; the length of the reproductive life of males and females; what proportion of adult males are subject to fishing mortality; how successful small males are at fertilizing females. Such studies will indicate the

effect on reproduction of harvesting various numbers of large and small adult male crabs.

Knowledge of the age-size relationship is necessary for identifying pre-recruit crabs by year class and determining the number of year classes in the fishery. Setting minimum size limits and yearly harvest quotas should be based on the growth rate of small mature males and the abundance of the various year classes.

Finally, studies should be conducted to establish seasonal, spatial, and bathymetric distribution of snow crabs with respect to sex and age. This is important in delineating rearing and mating areas, migrations, and age structure in the population.

APPENDIX A

Selected References to the Genus *Chionoecetes*

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APPENDIX B

Maturity Index and Egg Stage

by Date of Collection

I. Maturity Index

1-22-73	3-10-73	5-19-73	8-15-73	10-21-73	4-15-74
8.0	3.5	0.3	4.2	—	12.6
6.8	8.0	0.3	4.3		14.2
9.2	3.2	0.5	5.0		15.1
7.5	9.3	0.3	5.6		18.2
7.4	4.6	0.4	3.9		13.2
7.5	9.0	0.5	3.3		17.6
5.7	3.0	0.2	4.3		10.6
6.3	6.1	0.1	4.5		15.1
5.3	4.4	0.1	3.5		15.2
7.5	7.0	0.1	3.8		3.8
6.5	7.2	0.1	2.0		17.6
	8.6	0.2			7.5
	4.3	0.2			15.9
	4.5	0.2			16.8
	4.3	0.3			13.6
		0.3			13.8
		0.3			18.0
		0.5			18.4
		0.4			14.3
		0.4			13.3

II. Egg Stage

1-22-73	3-10-73	5-19-73	8-15-73	10-21-73	4-15-74
5	7	2	2	4	9
5	7	2	2	4	9
5	7	2	3		9
5	7	2.5	3		9
5	7	2.5	3		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3	4		9
5	7	3			9
	7	3			9
	7	3			9
	7	3			9
	7	3			9
	7	3			9
	7	3			9
	7	3.5			9

Egg stage (continued)

1-22-73	3-10-73	5-19-73	8-15-73	10-21-73	4-15-74
	7	3.5			
	7	4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			
		4			

APPENDIX C

Egg Number By Carapace Width

I. Summer

Width	Egg No.	Width	Egg No.	Width	Egg No.
77	72,000	89	152,000	99	57,000
78	109,000	90	121,000	99	190,000
79	58,000	90	148,000	99	218,000
79	100,000	90	168,000	99	225,000
80	64,000	90	221,000	99	244,000
81	137,000	92	79,000	100	170,000
83	111,000	92	139,000	100	191,000
83	113,000	92	165,000	100	218,000
85	78,000	92	179,000	100	236,000
85	101,000	92	181,000	100	237,000
85	228,000	92	185,000	100	248,000
87	99,000	94	150,000	101	56,000
87	102,000	94	167,000	101	100,000
87	134,000	95	55,000	101	188,000
87	172,000	95	75,000	101	211,000
88	86,000	95	143,000	101	215,000
88	90,000	97	157,000	101	315,000
88	112,000	98	34,000	102	120,000
89	122,000	98	186,000	102	173,000
89	127,000	98	200,000	102	196,000

Summer (continued)

Width	Egg No.	Width	Egg No.	Width	Egg No.
102	208,000	104	270,000	108	106,000
102	221,000	105	176,000	108	203,000
102	276,000	105	239,000	108	250,000
103	42,000	105	261,000	108	293,000
103	243,000	105	286,000	109	158,000
103	276,000	106	195,000	109	284,000
104	121,000	107	44,000	109	317,000
104	135,000	107	209,000	111	222,000
104	154,000	107	240,000	113	262,000
104	157,000	107	298,000		
II. Spring					
82	91,000	85	131,000	88	173,000
83	138,000	85	137,000	89	143,000
84	63,000	86	34,000	89	158,000
84	105,000	86	112,000	89	168,000
84	120,000	86	119,000	90	93,000
85	60,000	86	136,000	91	24,000
85	77,000	88	49,000	91	82,000
85	78,000	88	80,000	91	111,000
85	112,000	88	109,000	92	90,000
85	113,000	88	158,000	92	103,000

Spring (continued)

Width	Egg No.	Width	Egg No.	Width	Egg No.
92	127,000	99	109,000	105	170,000
93	103,000	99	164,000	105	221,000
94	130,000	100	133,000	106	147,000
94	139,000	100	144,000	107	77,000
94	143,000	100	176,000	107	154,000
94	172,000	100	207,000	107	238,000
96	107,000	101	152,000	107	244,000
96	124,000	101	152,000	108	103,000
96	127,000	101	183,000	108	127,000
96	128,000	101	204,000	108	220,000
96	131,000	102	39,000	109	160,000
96	166,000	102	140,000	109	180,000
97	116,000	102	147,000	110	40,000
97	133,000	102	157,000	110	117,000
97	135,000	103	155,000	110	127,000
97	159,000	103	198,000	111	154,000
98	24,000	104	104,000	113	247,000
98	173,000	104	141,000	115	66,000
99	97,000	104	207,000	116	318,000
99	108,000	105	128,000		

APPENDIX D

Sex Ratio by IPHC Trawl Station

Station	Depth	Females	Males	Total	Percent Females	Av. Size Females
75B	35	0	0	0	0	—
75D	37	0	0	0	0	—
76A	43	148	215	363	41	43
76B	42	6	11	17	35	51
77A	25	7	9	16	44	36
77B	61	2750	4950	7700[a]	36	45
77E	45	50	78	128	39	61
77F	53	130	136	266	49	67
77G	55	1	1	2	50	35
78A	40	792	837	1629[b]	49	46
78B	58	1820	2090	3910[a]	47	50
78C	51	43	55	98	44	51
78E	53	63	32	95	66	68
78F	57	2	1	3	67	74
78G	59	9	7	16	56	38
79A	27	0	1	1	0	—
79B	69	135	208	343	39	44
79C	59	219	286	505	43	48
79E	62	0	2	2	0	—
79F	61	5	4	9	56	62

Sex Ratio (continued)

Station	Depth	Females	Males	Total	Percent Females	Av. Size Females
79G	66	4	3	7	57	67
80A	21	2	3	5	40	36
80B	70	65	69	134	49	48
80C	67	304	359	663	46	44
80D	67	22	15	37	59	54
80E	67	2	5	7	29	44
81B	34	21	17	38	55	39
81C	57	162	201	363	44	44
82A	15	6	1	7	86	58
82B	96	43	49	92	47	37
82C	125	13	12	25	52	34
82D	63	1460	1380	2840[a]	51	44
82E	46	20	16	36	57	39
83A	9	93	48	141	66	59
83B	52	4680	4090	8770[a]	53	56
83D	42	7	12	19	37	43

a - based on a 10% subsample

b - based on a 33% subsample

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